RADIONUCLIDES

FACT SHEET

See related Fact Sheets: Acronyms & Abbreviations; Glossary of Terms; Cost Assumptions; Raw Water Composition; Total Plant Costs; and WaTER Program.

1. CONTAMINANT DATA

A. Chemical Data: Radioactive elements are often called radioactive isotopes or radionuclides. Radionuclides emit radiant atomic energy caused by the spontaneous disintegration of the nuclei of their atoms, resulting in radioactive particles or decay products that are members of the radioactive elements. As radionuclides decay, they emit ionizing radiation in the form of alpha (α) or beta (β) particles and gamma (γ) photons. Alpha particles are relatively massive and easy to stop. They typically travel 100 μm into tissue while beta particles may travel several centimeters. Gamma rays, having no charge or mass, are simply a form of electromagnetic radiation, that travel at the speed of light. Gamma rays have short wavelengths and therefore are capable of causing ionizations; as such they are biologically damaging. Generally, the soluble radionuclides of concern in water include: Radon (Rn), atomic number 86, atomic weight 222, a gas; Uranium (U), atomic number 92, atomic weight 238.03, a metal; and combined Radium-226/228 (Radium (Ra), atomic number 88, atomic weight 226.03, a metal). The three forms of radioactivity, α, β, and γ are also a concern.

B. Source in Nature: Radionuclides are both natural and man-made and are found in air, water, soil, plants, and the human body. Rn gas is especially widespread in soils, rocks, and granite, and is created by the decay of the U and Ra series. Several small sources of radiation exist in the home and persons in many occupations encounter radiation. Medical uses for radiation include therapy and diagnosis. This Fact Sheet is concerned with the soluble natural radionuclides found in water. Radionuclides in water are ingested by either drinking contaminated water or eating food that has been washed in the water. In the case of Rn, exposure occurs from inhalation of the gas or decay products released from water during household use. Higher levels of Rn are generally found in groundwater rather than surface water.

C. SDWA Limits (currently under review): Current or proposed limits include: Rn=300 pCi/L; U=0.02 pCi/L; Alpha Emitters (including Radium-226 but excluding Rn and U)=15 pCi/L; Beta/Photon Emitters=4 mrem/yr; and combined Radium-226/228=5 pCi/L. When finalized, the Radionuclide Rule will exclude Rn and U, which will have their own individual standards.

USEPA is scheduled to propose revised standard for Rn by 8/1/1999 and promulgate final rule by 8/1/2001; and promulgate final rules for U and the complete Radionuclides Rule by 8/1/2000.

D. Health Effects of Contamination: Radionuclides are known human carcinogens. All three forms of radiation are dangerous to living things. Rn is associated with lung cancer; Radium-226 is associated with bone sarcomas and head carcinomas; and Radium-228 is associated with bone sarcomas. Other health effects include kidney damage and birth defects. Low level exposures can cause somatic and/or genetic defects. Somatic defects may include a higher risk of cancer, sterility, cataracts, or reduced life span. Genetic defects may include chromosome damage.

Protection against the three forms of radiation differ significantly. Our skin is sufficient protection for α emitters external to the body, however taken internally, such as inhalation, α particles can be extremely dangerous. Beta particles can be stopped with shielding (i.e. 1 cm of aluminum). Gamma rays may require several centimeters of lead to provide adequate shielding.

2. REMOVAL TECHNIQUES

A. USEPA BAT (currently under review):

BAT / Radionuclide	AS	GAC	IX	RO	Lime softening	Coagulation & filtration
Rn	X	X				
U			anion	X	X	X
α				X		
β			mixed bed	X		
Ra			cation	X	X	

! AS use towers filled with material, whereby water enters the top of the tower, is sprayed over the material exposing a thin layer of water to countercurrent air being blown in at the bottom. The process allows for mass transfer of the Rn from water into air. AS off-gas is either discharged to the atmosphere or treated by vapor phase GAC. Benefits: removal efficiencies greater than 99.9%; best suited large installations. Limitations: risks associated with off-gassed Rn; requires ample space; requires careful monitoring.

! GAC uses extremely porous carbon media in a process known as adsorption. As water passes through the media, the dissolved contaminants are attracted and held (adsorbed) on the solid surface. Benefits: well established; suitable for home use. Limitations: too expensive for large systems; less effective than aeration; requires careful monitoring. GAC cost curves will be included in a future revision.

! IX uses selectively charged resins to exchange acceptable ions from the resin for radionuclides in the water. Benefits: effective; well developed. Limitations: restocking of salt supply; regular regeneration; concentrate disposal.

! RO uses a semipermeable membrane, and the application of pressure to a concentrated solution which causes water, but not suspended or dissolved solids (radionuclides), to pass through the membrane. Benefits: produces high quality water. Limitations: cost; pretreatment/feed pump requirements; concentrate disposal.

! Lime softening uses $Ca(OH)_2$ in sufficient quantity to raise the pH to about 10 to precipitate carbonate hardness and heavy metals, like Ra. Benefits: lower capital costs; proven and reliable. Limitations: operator care required with chemical usage; sludge disposal.

! Coagulation and filtration uses the conventional treatment processes of chemical addition, coagulation, and dual media filtration. Benefits: low capital costs for proven, reliable process. Limitations: operator care required with chemical usage; sludge disposal.

B. Alternative Methods of Treatment: Distillation heats water until it turns to steam. The steam travels through a condenser coil where it is cooled and returned to liquid. The dissolved solids (radionuclides) remain in the boiler section. Distillation is not effective for Rn gas.

C. Safety and Health Requirements for Treatment Processes: Personnel involved with demineralization treatment processes should be aware of the chemicals being used (MSDS information), the electrical shock hazards, and the hydraulic pressures required to operate the equipment. General industry safety, health, and self protection practices should be followed, including proper use of tools.

3. BAT PROCESS DESCRIPTION AND COST DATA

General Assumptions: Refer to: Raw Water Composition Fact Sheet for ionic concentrations; and Cost Assumptions Fact Sheet for cost index data and process assumptions. All costs are based on *ENR*, PPI, and BLS cost indices for March 2001. General sitework, building, external pumps/piping, pretreatment, or off-site sludge disposal are not included.

3A. Air Stripping for Rn Removal:

Process - AS is a physical separation process. Packed tower AS may use a tall, cylindrical tower filled with packing material. Water enters the top of the tower and is sprayed over the packing material exposing a thin layer of water to the countercurrent air being blown in at the bottom of the tower. The process maximizes the surface area of the water and allows for mass transfer of the Rn from water into air. Maximum volatilization occurs when the water is evenly distributed and the countercurrent air is evenly applied, even when a load change occurs. Treated water exits the bottom of the tower, while air containing the volatilized contaminants is vented to atmosphere or treated by vapor phase GAC. Air emissions above Clean Air Act standards must be treated prior to release. A variety of packing materials are available, or plastic elements may be used in place of packing material. Auxiliary equipment can include: automated controls and level switches or safety features such as differential pressure monitors. Alternate types of ASs include: aeration tanks, spray aeration, shallow trays, columns filled with chemical resistant ellipsoids, or cascade-type internal components.

Vapor phase GAC is similar to liquid phase GAC. It uses extremely porous carbon media in a process known as adsorption. As air passes through the highly porous media which has an extremely high surface area for adsorption, the volatilized contaminants adsorb on the solid surface. The treated air is discharged directly to the atmosphere. Careful selection of type of carbon to be used is based on the contaminants in the air, and manufacturer's recommendations.

Pretreatment - Chlorination and dechlorination for routine cleaning of scale, slime, and clogging may be required. With high TSS waters, prefiltration may be required.

Posttreatment - Postdisinfection of AS effluent may be required. Polishing of AS off-gas may be required.

Maintenance - Careful monitoring and testing to ensure contaminant removal. Packed tower ASs are subject to chemical/physical scaling of the equipment as a result of hardness or sliming of the packing material due biological growth. Regular replacement of vapor phase carbon media is required and is based on contaminant type, concentration, rate of water usage, and type of carbon used.

Waste Disposal - When large amounts of raw water with high levels of radioactive materials are treated for sufficiently long periods of time, the waste products can become radioactive enough to cause concern about safe and legal disposal. Waste products (i.e. GAC and cleaning solutions) require disposal in accordance with local or state regulations. The USEPA guidance entitled *Suggested Guidelines for Disposal of Drinking Water Treatment Wastes Containing Radioactivity*, dated June 1994, provides disposal information. Costs associated with waste disposal should be considered significant.

Advantages -
- Well established.
- Rn readily escapes from water into air.
- Low air/water ratios are sufficient which leads to lower O&M requirements and costs.
- Packed towers are more effective, but tray configurations are less susceptible to fouling and are easier to clean.

Disadvantages -
- Requires design by knowledgeable, experienced individual with specifics on water flow rate, air-to-water ratio, influent concentrations, water temperature, and atmospheric pressure. Design is based on Henry's Law Constant, which describes the relation between the distribution of a substance in the liquid and the gas phases where ideal conditions exist. Computer programs are available to assist with modeling, and most manufacturer's have programs for modeling their specific equipment.
- Risks associated with the off-gassed Rn.
- Fouling potential from the precipitation of Mn and Fe oxides.
- Risks of increases of Pb and Cu in some tap water due to increases in corrosivity of treated water.

Costs - The application of AS is extremely site specific. The costs of the equipment and operation and maintenance are based on the site specific organics and Rn concentrations. Because the organics and Rn concentrations vary greatly from location to location, a typical raw water analysis on which to base generic costs is impractical. For these reasons generic costs are not provided.

3B. Granular Activated Carbon for Rn Removal:
Process - GAC uses extremely porous carbon media in a process known as adsorption. As water passes through the highly porous media which has an extremely high surface area for adsorption, the dissolved contaminants adsorb on the solid surface. GAC is made of tiny clusters of carbon atoms stacked upon one another. The carbon media is produced by heating the carbon source (generally activated charcoal) in the absence of air to produce a high carbon material. The carbon media is activated by passing oxidizing gases through the material at extremely high temperatures. The activation process produces the pores that result in such high adsorption properties. The adsorption process depends on the following factors: 1) physical properties of the GAC, such as type of raw carbon, method of activation, pore size distribution, and surface area; 2) the chemical/electrical nature of the carbon source or method of activation, and the amount of oxygen and hydrogen associated with them, such that as the carbon surfaces become filled the more actively adsorbed contaminants will displace the less actively adsorbed ones; 3) chemical composition and concentration of contaminants, such as size, similarity, and concentration; 4) the temperature and pH of the water, adsorption usually increases as temperature and pH decrease; and 5) the flowrate and exposure time to the GAC, in that low contaminant concentration and flowrate with extended contact times increase the carbon's life. GAC devices include: pour-through for treating small volumes; faucet-mounted (with or without by-pass) for single point use; in-line (with or without by-pass) for treating large volumes at several faucets; and high-volume commercial units for treating community water supply systems. Careful selection of type of carbon to be used is based on the contaminants in the water, and manufacturer's recommendations.

Pretreatment - With bacterially unstable waters, filtration and disinfection prior to carbon treatment may be required. With high TSS waters, prefiltration may be required.

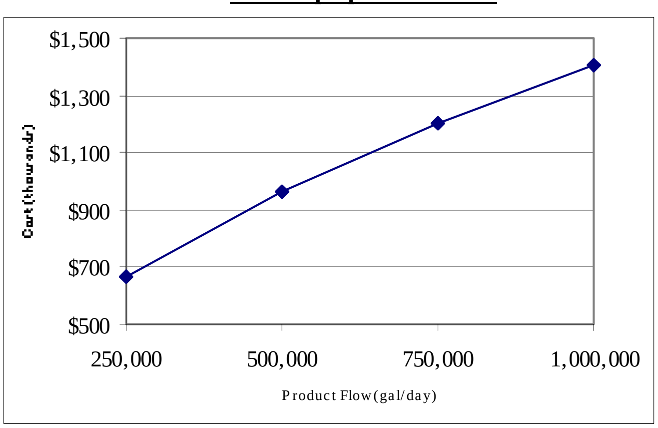
Maintenance - Careful monitoring and testing to ensure contaminant removal is required. Regular replacement of carbon media is required and is based on contaminant type, concentration, rate of water usage, and type of carbon used. The manufacturer's recommendations for media replacement should be consulted. Recharging by backwashing or flushing with hot water (145^{o}F) may release the adsorbed Rn gas and any organic chemicals. With bacterially unstable waters, monitoring for bacterial growth is required because the adsorbed organic chemicals are a food source for some bacteria. Flushing is required if the carbon filter is not used for several days, and regular backwashing may be required to prevent bacterial growth. Perform system pressure and flowrate checks to verify backwashing capabilities. Perform routine maintenance checks of valves, pipes, and pumps.

Waste Disposal - When large amounts of raw water with high levels of radioactive materials are treated for sufficiently long periods of time, the waste products can become radioactive enough to cause concern about safe and legal disposal. Waste products (i.e. GAC, backwash water, and cleaning solutions) require disposal in accordance with local or state regulations. The USEPA guidance entitled *Suggested Guidelines for Disposal of Drinking Water Treatment Wastes Containing Radioactivity*, dated June 1994, provides disposal information. As a result of the wide variances in local and state laws, the costs presented below do not address waste disposal. However, costs associated with waste disposal should be considered significant. Disposal of spent GAC may be offered by the contractor providing the media replacement services.

Advantages -
- Well established.
- Suitable for small systems, or even home use, providing disposal of spent carbon can be addressed.
- Typically inexpensive, with simple filter replacement requirements.
- Improves taste and smell; removes chlorine.

Disadvantages -
- Too expensive for large systems.
- Susceptible to sudden removal-efficiency drop-offs.
- Bacteria may grow on carbon surface.
- Adequate water flow and pressure required for backwashing/flushing.
- Requires careful monitoring and disposal of spent carbon.
- Less effective than aeration.

BAT Equipment Cost*



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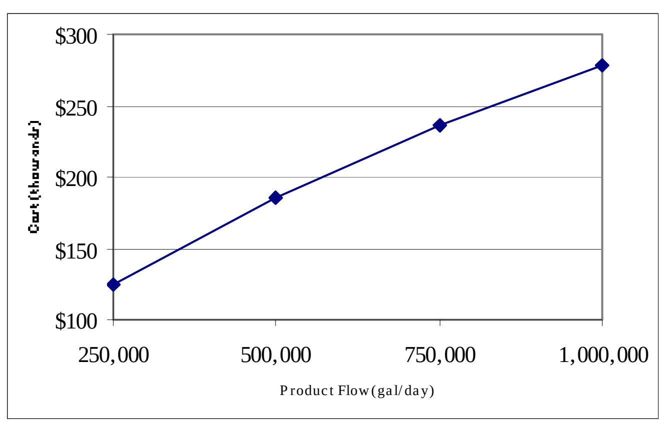


*Refer to Cost Assumptions Fact Sheet. Does not include general sitework, building, external pumps/piping, pretreatment, or off-site sludge disposal.

3C-a. Anion Ion Exchange for U Removal:
Process - Anion IX is a reversible chemical process in which ions from an insoluble, permanent, solid resin bed are exchanged for ions in water. The process relies on the fact that water solutions must be electrically neutral, therefore ions in the resin bed are exchanged with ions of similar charge in the water. As a result of the exchange process, no reduction in ions is obtained. IX operation for U removal begins with a fully recharged resin bed, having enough Cl^- or OH^- ions to carry out the anion exchange. Usually a polymer resin bed is composed of millions of medium sand grain size, spherical beads. As water passes through the resin bed, the negatively charged Cl^- or OH^- ions are released into the water, being substituted or replaced with the soluble, negatively charged U compounds in the water (ion exchange). When the resin becomes exhausted of Cl^- ions, the bed must be regenerated by passing a strong, usually NaCl (or KCl), solution over the resin bed, displacing the negatively charged U compounds with Cl^- ions. Current resins are not compound selective and may remove other anions before removing negatively charged U compounds. Therefore IX requires careful consideration of the raw water characteristics. Typically, IX for negatively charged U compounds utilizes a Cl^- or OH^- strongly basic anion resin bed.

Pretreatment - Guidelines are available on accepted limits for pH, organics, turbidity, and other raw water characteristics. Pretreatment may be required to reduce excessive amounts of TSS which could plug the resin bed, and typically includes media or carbon filtration.

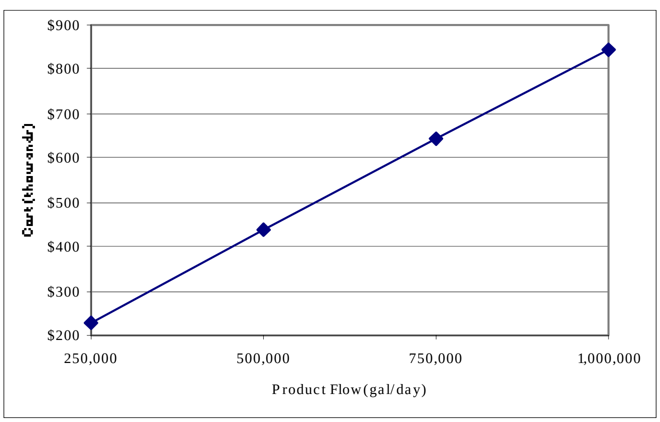
Maintenance - The IX resin requires regular regeneration, the frequency of which depends on raw water characteristics and the U concentration. Preparation of the NaCl solution is required. If utilized, filter replacement and backwashing will be required.

Waste Disposal - When large amounts of raw water with high levels of radioactive materials are treated for sufficiently long periods of time, the waste products can become radioactive enough to cause concern about safe and legal disposal. Waste products (i.e. resin, backwash water, and cleaning solutions) require disposal in accordance with local or state regulations. The USEPA guidance entitled *Suggested Guidelines for Disposal of Drinking Water Treatment Wastes Containing Radioactivity*, dated June 1994, provides disposal information. As a result of the wide variances in local and state laws, the costs presented below do not address waste disposal. However, costs associated with waste disposal should be considered significant.

Advantages -
- ! Ease of operation; highly reliable.
- ! Lower initial cost; resins will not wear out with regular regeneration.
- ! Effective; widely used.
- ! Suitable for small and large installations.
- ! Variety of specific resins are available for removing specific contaminants.

Disadvantages -
- ! Requires salt storage.
- ! Strongly basic anion resins are susceptible to organic fouling; reduced life; thermodynamically unstable.
- ! Usually not feasible with high levels of TDS.
- ! Resins are sensitive to the presence of competing ions.

BAT Equipment Cost*



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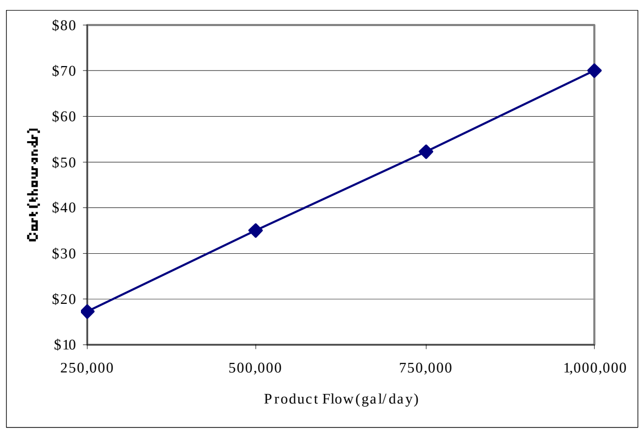


*Refer to Cost Assumptions Fact Sheet. Does not include general sitework, building, external pumps/piping, pretreatment, or off-site sludge disposal.

3C-b. Cation Ion Exchange for Ra Removal:

Process - Cation IX is a reversible chemical process in which ions from an insoluble, permanent, solid resin bed are exchanged for ions in water. The process relies on the fact that water solutions must be electrically neutral, therefore ions in the resin bed are exchanged with ions of similar charge in the water. As a result of the exchange process, no reduction in ions is obtained. IX operation for Ra removal begins with a fully recharged resin bed, having enough Na^+ or K^+ ions to carry out the cation exchange. Usually a polymer resin bed is composed of millions of medium sand grain size, spherical beads. As water passes through the resin bed, the negatively charged Na^+ ions are released into the water, being substituted or replaced with the soluble, positively charged Ra compounds in the water (ion exchange). When the resin becomes exhausted of Na^+ ions, the bed must be regenerated by passing a strong, usually NaCl (or KCl), solution over the resin bed, displacing the positively charged Ra compounds with Na^+ ions. Current resins are not compound selective and may remove other cations before removing positively charged Ra compounds. Therefore IX requires careful consideration of the raw water characteristics. Typically, IX for positively charged Ra compounds utilizes a Cl^- or OH^- strongly acid cation resin bed.

Pretreatment - Guidelines are available on accepted limits for pH, organics, turbidity, and other raw water characteristics. Pretreatment may be required to reduce excessive amounts of TSS which could plug the resin bed, and typically includes media or carbon filtration.

Maintenance - Depending on raw water characteristics and Ra concentration, the resin will require regular regeneration with a NaCl solution. Preparation of the NaCl solution is required. If utilized, filter replacement and backwashing will be required.

Waste Disposal - When large amounts of raw water with high levels of radioactive materials are treated for sufficiently long periods of time, the waste products can become radioactive enough to cause concern about safe and legal disposal. Waste products (i.e. resin, backwash water, and cleaning solutions) require disposal in accordance with local or state regulations. The USEPA guidance entitled *Suggested Guidelines for Disposal of Drinking Water Treatment Wastes Containing Radioactivity*, dated June 1994, provides disposal information. As a result of the wide variances in local and state laws, the costs presented below do not address waste disposal. However, costs associated with waste disposal should be considered significant.

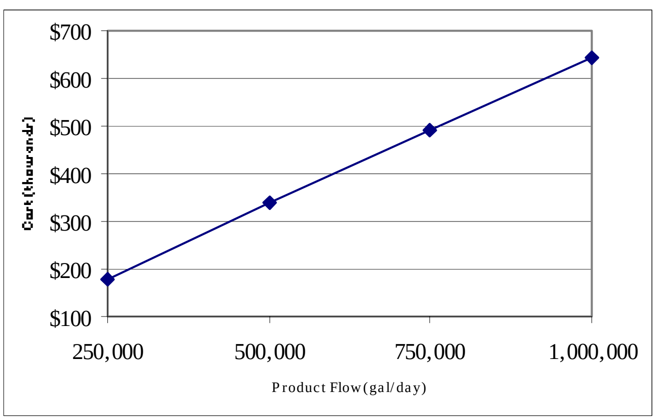
Advantages -

- Ease of operation; highly reliable.
- Lower initial cost; resins will not wear out with regular regeneration.
- Effective; widely used.
- Suitable for small and large installations.
- Variety of specific resins are available for removing specific contaminants.

Disadvantages -

- Requires salt storage.
- Usually not feasible with high levels of TDS.
- Resins are sensitive to the presence of competing ions.

BAT Equipment Cost*



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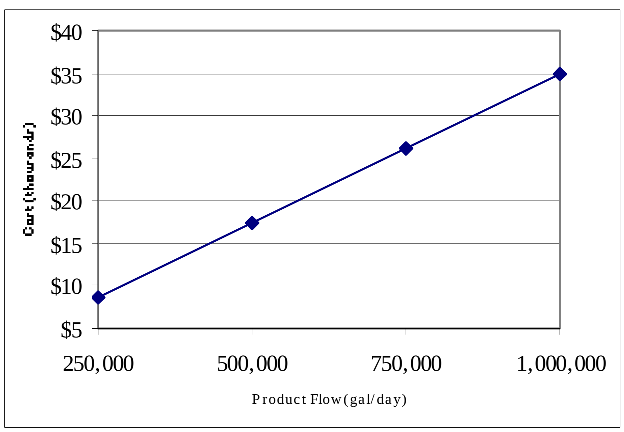


*Refer to Cost Assumptions Fact Sheet. Does not include general sitework, building, external pumps/piping, pretreatment, or off-site sludge disposal.

3C-c. Mixed Bed Ion Exchange for β Removal:

Process - Mixed bed IX is a reversible chemical process in which ions from an insoluble, permanent, solid resin bed are exchanged for ions in water. The process relies on the fact that water solutions must be electrically neutral, therefore ions in the resin bed are exchanged with ions of similar charge in the water. As a result of the exchange process, no reduction in ions is obtained. IX operation for Gross Beta (β) Particle Activity and Photon Emitter removal begins with a fully recharged resin bed, having enough positive and negative ions to carry out the cation and anion exchange. Usually a polymer resin bed is composed of millions of medium sand grain size, spherical beads. As water passes through the resin bed, the negatively charged Na^+ or Cl^- ions are released into the water, being substituted or replaced with the soluble, positively or negatively charged β compounds in the water (ion exchange). When the resin becomes exhausted of Na^+ or Cl^- ions, the bed must be regenerated by passing a strong, usually NaCl (or KCl), solution over the resin bed, displacing the positively or negatively charged β compounds with Na^+ or Cl^- ions. Current resins are not compound selective and may remove other cations/anions before removing positively/negatively charged β compounds. Therefore IX requires careful consideration of the raw water characteristics. Typically, IX for β compounds utilizes a mixed Na^+ and Cl^- strongly acid/basic cation/anion resin bed.

Pretreatment - Guidelines are available on accepted limits for pH, organics, turbidity, and other raw water characteristics. Pretreatment may be required to reduce excessive amounts of TSS which could plug the resin bed, and typically includes media or carbon filtration.

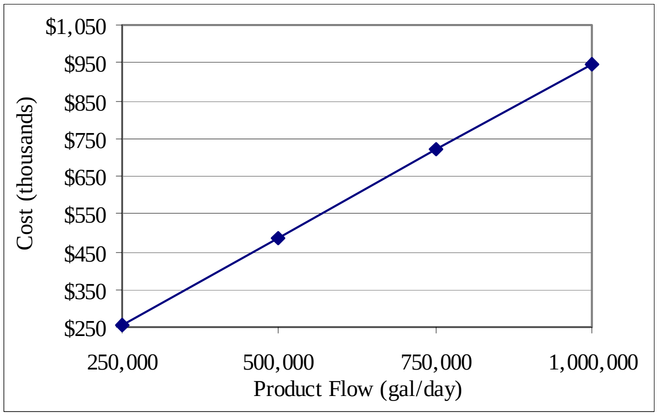
Maintenance - Depending on raw water characteristics and β concentration, the resin will require regular regeneration with a NaCl solution. Preparation of the NaCl solution is required. If utilized, filter replacement and backwashing will be required.

Waste Disposal - When large amounts of raw water with high levels of radioactive materials are treated for sufficiently long periods of time, the waste products can become radioactive enough to cause concern about safe and legal disposal. Waste products (i.e. resin, backwash water, and cleaning solutions) require disposal in accordance with local or state regulations. The USEPA guidance entitled *Suggested Guidelines for Disposal of Drinking Water Treatment Wastes Containing Radioactivity*, dated June 1994, provides disposal information. As a result of the wide variances in local and state laws, the costs presented below do not address waste disposal. However, costs associated with waste disposal should be considered significant.

Advantages -
- ! Ease of operation; highly reliable.
- ! Lower initial cost; resins will not wear out with regular regeneration.
- ! Effective; widely used.
- ! Suitable for small and large installations.
- ! Variety of specific resins are available for removing specific contaminants.

Disadvantages -
- ! Requires salt storage.
- ! Usually not feasible with high levels of TDS.
- ! Resins are sensitive to the presence of competing ions.

BAT Equipment Cost*



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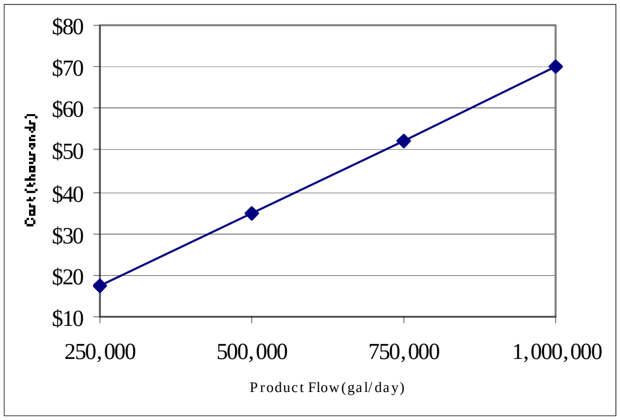


*Refer to Cost Assumptions Fact Sheet. Does not include general sitework, building, external pumps/piping, pretreatment, or off-site sludge disposal.

3D. Reverse Osmosis for U, α, β, and Ra Removal:

Process - RO is a physical process in which contaminants are removed by applying pressure on the feed water to direct it through a semipermeable membrane. The process is the "reverse" of natural osmosis (water diffusion from dilute to concentrated through a semipermeable membrane to equalize ion concentration) as a result of the applied pressure to the concentrated side of the membrane, which overcomes the natural osmotic pressure. RO membranes reject ions based on size and electrical charge. The raw water is typically called feed; the product water is called permeate; and the concentrated reject is called concentrate. Common RO membrane materials include asymmetric cellulose acetate or polyamide thin film composite. Common membrane construction includes spiral wound or hollow fine fiber. Each material and construction method has specific benefits and limitations depending upon the raw water characteristics and pretreatment. A typical large RO installation includes a high pressure feed pump, parallel 1st and 2nd stage membrane elements (in pressure vessels); valving; and feed, permeate, and concentrate piping. All materials and construction methods require regular maintenance. Factors influencing membrane selection are cost, recovery, rejection, raw water characteristics, and pretreatment. Factors influencing performance are raw water characteristics, pressure, temperature, and regular monitoring and maintenance.

Pretreatment - RO requires a careful review of raw water characteristics and pretreatment needs to prevent membranes from fouling, scaling, or other membrane degradation. Removal of suspended solids is necessary to prevent colloidal and bio-fouling, and removal of dissolved solids is necessary to prevent scaling and chemical attack. Large installation pretreatment can include media filters to remove suspended particles; ion exchange softening or antiscalant to remove hardness; temperature and pH adjustment to maintain efficiency; acid to prevent scaling and membrane damage; activated carbon or bisulfite to remove chlorine (postdisinfection may be required); and cartridge (micro) filters to remove some dissolved particles and any remaining suspended particles.

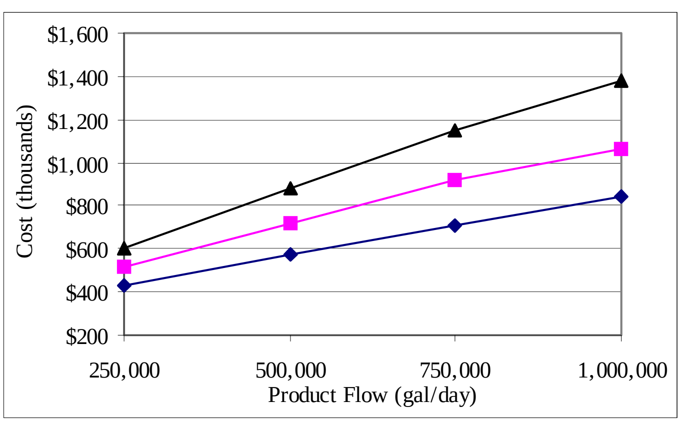
Maintenance - Monitor rejection percentage to ensure U and Ra removal below MCL. Regular monitoring of membrane performance is necessary to determine fouling, scaling, or other membrane degradation. Use of monitoring equations to track membrane performance is recommended. Acidic or caustic solutions are regularly flushed through the system at high volume/low pressure with a cleaning agent to remove fouling and scaling. The system is flushed and returned to service. $NaHSO_3$ is a typical caustic cleaner. RO stages are cleaned sequentially. Frequency of membrane replacement dependent on raw water characteristics, pretreatment, and maintenance.

Waste Disposal - When large amounts of raw water with high levels of radioactive materials are treated for sufficiently long periods of time, the waste products can become radioactive enough to cause concern about safe and legal disposal. Waste products (i.e. filters, elements, backwash water, and cleaning solutions) require disposal in accordance with local or state regulations. The USEPA guidance entitled *Suggested Guidelines for Disposal of Drinking Water Treatment Wastes Containing Radioactivity*, dated June 1994, provides disposal information. As a result of the wide variances in local and state laws, the costs presented below do not address waste disposal. However, costs associated with waste disposal should be considered significant.

Advantages -
- ! Produces highest water quality.
- ! Can effectively treat wide range of dissolved salts and minerals, turbidity, health and aesthetic contaminants, and certain organics; some highly-maintained units are capable of treating biological contaminants.
- ! Low pressure (<100 psi), compact, self-contained, single membrane units are available for small installations.

Disadvantages -
- ! Relatively expensive to install and operate.
- ! Frequent membrane monitoring and maintenance; monitoring of rejection percentage for U and Ra removal.
- ! Pressure, temperature, and pH requirements to meet membrane tolerances. May be chemically sensitive.

BAT Equipment Cost*



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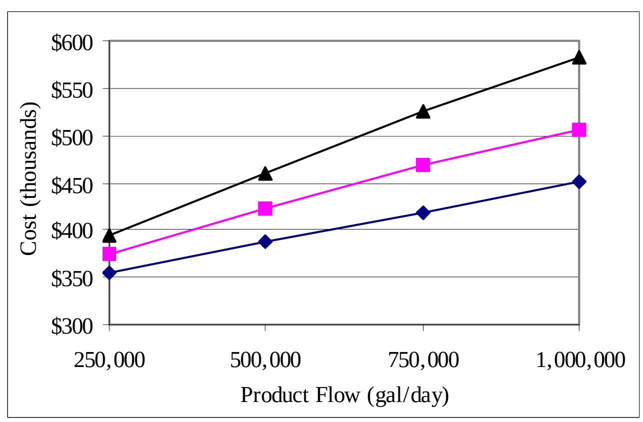
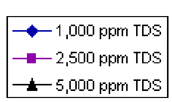




*Refer to Cost Assumptions Fact Sheet. Does not include general sitework, building, external pumps/piping, pretreatment, or off-site sludge disposal.

3E. Lime Softening for U and Ra Removal:
Process - Lime softening uses chemical additions followed by an upflow SCC to accomplish coagulation, flocculation, and clarification. Chemical additions include $Ca(OH)_2$ to precipitate carbonate and Na_2CO_3 to precipitate noncarbonate hardness. In the upflow SCC, coagulation, flocculation (agglomeration of the suspended material, including U and Ra, into larger particles), and final clarification occur. In the upflow SCC, the clarified water flows up and over the weirs, while the settled particles are removed by pumping or other collection mechanisms (i.e. filtration).

Pretreatment - Jar tests to determine optimum pH for coagulation, and resulting pH adjustment, may be required. Optimum pH is about 10.5 or higher.

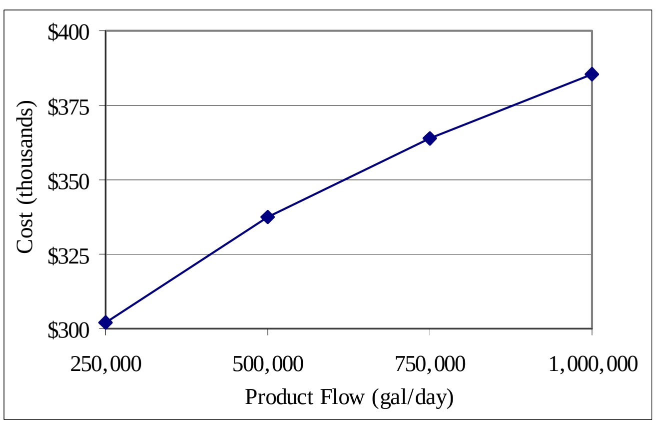
Maintenance - A routine check of chemical feed equipment is necessary several times during each work period to prevent clogging and equipment wear, and to ensure adequate chemical supply. All pumps, valves, and piping must be regularly checked and cleaned to prevent buildup of carbonate scale, which can cause plugging and malfunction. Similar procedures also apply to the sludge disposal return system, which takes the settled sludge from the bottom of the clarifier and conveys it to the dewatering and disposal processes.

Waste Disposal - When large amounts of raw water with high levels of radioactive materials are treated for sufficiently long periods of time, the waste products can become radioactive enough to cause concern about safe and legal disposal. Waste products (i.e. sludge and cleaning solutions) require disposal in accordance with local or state regulations. The USEPA guidance entitled *Suggested Guidelines for Disposal of Drinking Water Treatment Wastes Containing Radioactivity*, dated June 1994, provides disposal information. As a result of the wide variances in local and state laws, the costs presented below do not address waste disposal. However, costs associated with waste disposal should be considered significant.

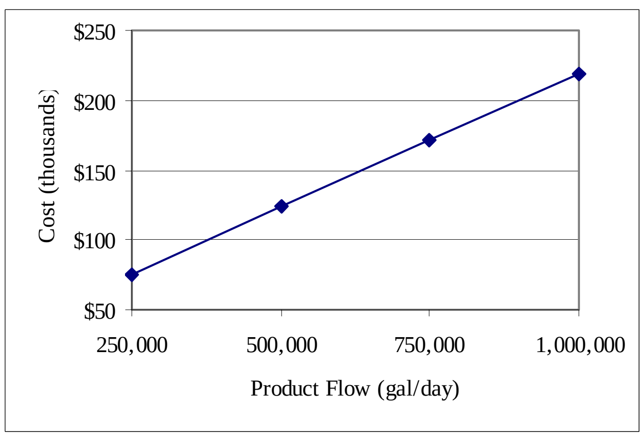
Advantages -
! Other heavy metals are also precipitated; reduces corrosion of pipes.
! Proven and reliable.
! Low pretreatment requirements.

Disadvantages -
! Operator care required with chemical handling.
! Produces high U and Ra-contaminated sludge volume.
! Sulfate may cause significant interference with removal efficiencies.

BAT Equipment Cost*



BAT Annual O&M Cost*



*Refer to Cost Assumptions Fact Sheet. Does not include general sitework, building, external pumps/piping, pretreatment, or off-site sludge disposal.

3F. Coagulation and Filtration for U Removal:

Process - Coagulation and filtration for uses the conventional chemical and physical treatment processes of chemical addition, rapid mix, coagulation with dry alum, flocculation, and dual media filtration. Chemical coagulation and flocculation consists of adding a chemical coagulant combined with mechanical flocculation to allow fine suspended and some dissolved solids to clump together (floc). $Al_2(SO_4)_3$ has been proven to be the most effective coagulant for U removal. Filtration provides final removal by dual media filtering of all floc and suspended solids.

Pretreatment - Jar tests to determine optimum pH for coagulation, and resulting pH adjustment, may be required.

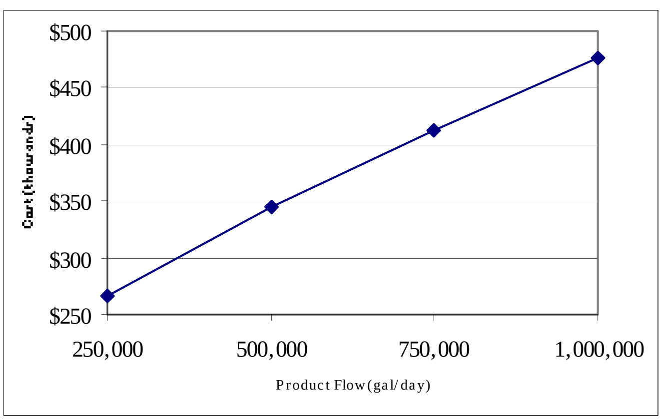
Maintenance - A routine check of chemical feed equipment is necessary several times during each work period to prevent clogging and equipment wear, and to ensure adequate chemical supply. All pumps, valves, and piping must be regularly checked and cleaned to prevent buildup of carbonate scale, which can cause plugging and malfunction. Routine checks of contaminant buildup in the filter is required, as well as filter backwash. Recharging or clean installation of media is periodically required.

Waste Disposal - When large amounts of raw water with high levels of radioactive materials are treated for sufficiently long periods of time, the waste products can become radioactive enough to cause concern about safe and legal disposal. Waste products (i.e. media, backwash water, and cleaning solutions) require disposal in accordance with local or state regulations. The USEPA guidance entitled *Suggested Guidelines for Disposal of Drinking Water Treatment Wastes Containing Radioactivity*, dated June 1994, provides disposal information. As a result of the wide variances in local and state laws, the costs presented below do not address waste disposal. However, costs associated with waste disposal should be considered significant.

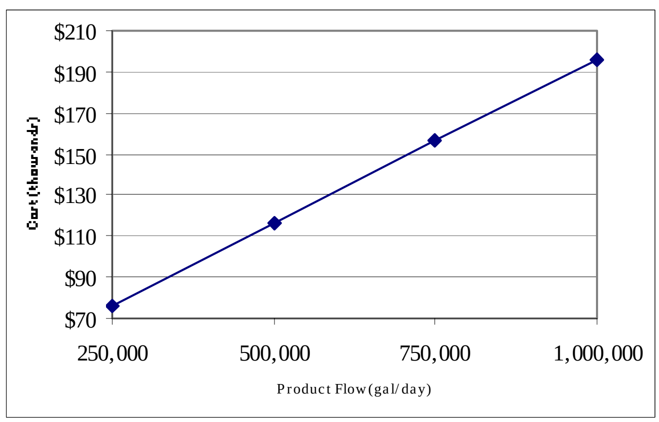
Advantages -
- Lowest capital costs.
- Lowest overall operating costs.
- Proven and reliable.
- Low pretreatment requirements.

Disadvantages -
- Operator care required with chemical handling.
- Produces high sludge volume.
- Sulfate may cause significant interference with removal efficiencies.

BAT Equipment Cost*



BAT Annual O&M Cost*



*Refer to Cost Assumptions Fact Sheet. Does not include general sitework, building, external pumps/piping, pretreatment, or off-site sludge disposal. Costs are presented for direct filtration (coagulation and flocculation plus filtration). Costs for coagulation and filtration would be less since flocculation is omitted.